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Using Material Flow Accounting to operationalize the concept of Society's Metabolism. A preliminary MFA for the United Kingdom for the period of 1937 – 1997

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ABSTRACT

This paper is attempting to do two things. Firstly, the notion of society's metabolism will be introduced as a main concept to contribute to the debate on the interaction between society and nature. This environmental debate was recently stimulated by the introduction of the idea of a possible sustainable development in the industrialised economies as a major political goal for the future. It will be argued here that accounting for society's metabolism is a crucial operationalization for the sustainability argument. Material Flow Accounting will be presented as a methodology to document the quantity and quality of the socio-economic metabolism of a given society. Further, it will concentrate on agreements for accounting and discuss the methodological assumptions developed within a decade of empirical work in the Social Ecology Team in Vienna.

Secondly, the paper attempts to establish the empirical data basis for the input side of the socio-economic metabolism for the UK economy covering the period from 1937 to 1997. Basically, this will be a very preliminary data set, which undoubtedly has to be discussed and improved within further empirical work. Nevertheless, it gives a first overview of the physical dimension of the UK economic activities over a rather long time period. The paper will discuss the quality of the data sources and indicate which parts of the data set can currently be regarded to be reliable and which still remain weak and therefore deserve further empirical efforts.

NON – TECHNICAL SUMMARY

In the 1970’s environmentalists have began to argue that society’s economic behaviour would lead to a global environmental crisis. This crisis, it has been argued, could in the last instance put the future of man as a whole at risk. Firstly, it has been recognised that toxic emissions could severely damage ecosystem functions. Shortly after, the environmental problem was portrayed as a side effect of economic growth. Most influential in those days, the Club of Rome report “Limits to growth” argued, that business as usual will inevitably reduce future quality of life. This idea of limits to growth was harshly criticised for both, its anti-capitalist argument against unlimited economic growth and its Neo-Malthusian perspective.

In the 1990’s, environmental and developmental issues were brought together in the new discourse of sustainable development. Under this new notion it has been argued that not economic growth as such is an environmental pressure, but the related material and energy flows mobilised by socio-economic activities. The question has been raised, if further economic growth could be gained with less environmental impact.

Clearly, this question requires not only an in-depth understanding of the interrelationship between society and nature but also an idea about the quantity and quality of the resource requirements an industrial society has. Once the situation is analysed and understood, one might think, society could cope with its sustainability problems. However, since it has been recognised that these questions would lead to rather complex answers, many attempts were undertaken to reduce complexity to support society’s capacity of self-observation. Extensive research led to numerous sets of environmental indicators, describing socio-economic pressures upon the environment, the state of nature and also society’s responses.

With the concept of a physical economy and society’s metabolism, and subsequently the idea of a physical accounting this report tries to look at the problem from a new perspective, aiming to introduce a more systematic idea of environmental indicators.

To do this, the paper refers to the theoretical concept of society’s metabolism and to material flow accounting as a methodology and technique to operationalize it. On the basis of this accounting framework, we establish an initial data set for the input side of material flows into the UK economy. Whereas the data set allows for numerous disaggregations, the report restricts itself to main categories like domestic extraction of biomass, mineral materials and fossil fuels and imported materials. These inputs are presented in time series for the period of 1937 to 1997.

The report refers to physical growth of the UK economy using indicators such as yearly direct material input. This direct material input into the UK economy accounted for an average of 410 million tons (or 8.5 tons per capita) in the 1940’s. After a period of rapid growth (average of 774 million tons in the 1970’s/14 tons per capita) physical growth came to a standstill. In the 1990’s direct material input accounts for an average of 777 million tons yearly (13.3 tons per capita).

To look at physical indicators derived from material flow accounting, instead of using monetary indicators, such as traditional environmental economics are using, offers a different perspective. In this perspective the economy is understood as part of the ecosphere, it is recognised that environmental problems can appear at every step in the extraction-production-consumption chain, and that it is not only problematic substances but also problematic quantities, which makes up society's sustainability problems. On the input side of socio-economic metabolism societies have to cope with scarcity problems, whereas on the output side, waste and emissions might override the absorption capacity of natural systems.

The paper introduces the idea of a characteristic metabolic profile of industrial societies. The main features of this characteristic industrial metabolic profile are, besides others, the comparably high amount of throughput, the growth dynamic, the low recycling rate, the over-use of air as a sink and the high amount of yearly net additions to stock.

Finally, the paper tries to present preliminary evidence, that the UK economy establishes a new post-industrial metabolic pattern. However, it seems that the stabilisation of resource input in the UK since the 1980's might rather be a story of structural change and to a lesser extent technological advancement than of an environmental sound policy.

INTRODUCTION

As the notion of sustainability has gained influence in the environmental discourse, the features of this discourse have changed remarkably. Under the notion of sustainability it was no longer the toxicity of some dangerous substances that was seen as the main problem of society's pressure upon the environment. The focus moved from the output side of the production system to a complete understanding of the physical dimension of the economy. From this point on, the economy was conceptualised as an activity, extracting materials from nature, transforming them, keeping them as society's stock for a certain amount of time and, in the end of the production-consumption chain, disposing of them again in nature. It has been recognised that environmental problems can arise at every step in this process. Furthermore, it has been understood that it is not only problematic substances but also problematic amounts of matter set in motion by society's activities that result in global environmental problems. Most often, the amount of input of a certain material predetermines the amount of output, such as is the case for CO_2 outputs, which are directly connected to fossil fuels inputs. Hence outputs can never decrease without a decrease of input since substances like CO_2 cannot be reduced by end of the pipe technologies.

A large amount of empirical research was stimulated by this new conceptualisation of society's environmental problem. This empirical work appears under the heading of Material Flow Accounting (MFA). Some of the research is rather technical whereas other researchers put the problem more theoretically, relating it to a wider concept of society's metabolism or, as it is sometimes better known, industrial metabolism (Fischer-Kowalski and Haberl 1993, 1997, Ayres and Simonis 1994).

The aim of Material Flow Accounting is to draw a complete picture of the physical dimension of a social system by capturing all material flows driven by these systems activities. The total amount and the progress through the economy of these materials is ideally reported within an accounting framework provided by MFA methodology. Most influential empirical work, alongside other work, has been done on economy-wide MFA concentrating on bulk material flow analysis.[1] National MFAs are readily available for a number of national economies yet, like for instance Germany, Austria, the Netherlands, Finland, the USA, Japan, Brazil and Italy. Others are following. One summary indicator derived from Material Flow Accounting, what is known as Direct Material Input, is discussed as a physical pendant to the overall GDP of an economy. Interestingly, some countries have already implemented this indicator within official statistics reporting systems.

This paper presents the concept of societies metabolism and its methodological implementation in the form of an accounting framework on material flows. Further, it provides a first, although still preliminary, data basis for an MFA of the UK economy.

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[1] Within the MFA community there are primarily two, at first sight different, approaches, material flow accounting (MFA) concentrating on materials and substance flow accounting (SFA) concentrating on chemical substances like for instance carbon, nitrogen, lead, chlorine and so on. Despite these differences, both approaches result in rather similar methodological assumptions. Moreover, due to methodological correspondance MFA can be linked to SFA rather easily.

The focus here lies on the material inputs to the UK economy and on the historical development of these inputs from 1937 to 1997.

The paper starts with the introduction of the theoretical notion of society's metabolism on the basis of which we develop some theoretical preconditions and criteria to guide the empirical work. More narrowly, we then concentrate on the technical aspects for accounting and describe the data sources used for our case study. We move on to empirical results for the United Kingdom, being mainly descriptive rather than analytic but nevertheless describing the main trends in resource use for the period from 1937 to 1997. We then will consider whether the UK economy fits into the pattern of a characteristic metabolic profile for industrialised societies or more likely establishes a new pattern of a post-industrialised metabolic profile.

THE THEORETICAL CONCEPT OF SOCIETIES METABOLISM

Metabolism is a concept taken from biology. In this scientific context, metabolism refers to the physiological processes within living beings describing the energy turnover connected to the conversion of matter, which is an inevitable feature for the reproduction of any organism. The notion can easily be widened from the individual organism to the relation between organisms. This ecological expansion actually took place in the history of the notion. In the place of the organism came nature as an entity representing a complex system of energy and material flows. Also a social version of metabolism was brought up referring to the problem of the interaction of society and nature. In the social interpretation the notion of metabolism refers to what is intentionally driven by society's activities rather than what unintentionally, automatically, happens.

Historically, the notion of metabolism stems from the materialist physiologist Jacob Moleschott, who concentrates on an ecological version of metabolism rather than on the biochemical conversion within organisms. He linked his idea of metabolism to the concept of conservation of matter. In a system where everything mutual attracts and is attracted, nothing can get lost, he argues. Consequently, the amount of available matter remains always the same (Moleschott 1887).

Karl Marx takes up Moleschott's concept in his economic analysis. He widened it to include the aspect of the intentional activity of men (society). For Marx, humans are part of the material world. In the same way natural processes not influenced by human activities are essentially part of matter and energy conversions the human production does not skip from this natural connection (Schmidt 1993).

In Marx, the notion of metabolism is a main feature in the analysis of the human interaction with nature. Although used metaphorically rather than empirically, the concept gains its explanatory power by linking the concept of the labour process to metabolism. It is within the labour process that man organises the inevitable supply of raw materials for production and reproduction of human societies. Therefore, Marx considers labour as a permanent necessity and a universal feature of humanity, independent of the way society is organised internally. Keeping in mind that Marx probably overestimates the transformative power of labour while leaving other intentional structures of the labour process theoretically underdeveloped (Benton 1989), the Marxian frame of analysis provides the main features for a socio-ecological analysis of society-nature interactions.

What are the underlying assumptions of the concept of society's metabolism? First, societies, like any organism, have to organise a constant throughput of matter and energy at least on the level of the biological minimum for their population. This can be regarded as a minimum condition for any society. Second, different from all other living beings, societies organise this resource throughput purposively, by even changing parameters of natural processes to gain better access to natures resource supply. This entails a wide range of purposive interventions in natural systems, where society's activities do not concentrate on extraction and transformation of resources but do intentionally change natural conditions.[2] Further, resource throughput is mobilised by labour. It is through labour, that raw materials are transformed to use values and are given a specific exchange value due to their capacity to be exchanged. Without inputs of concrete labour (or energy to drive machines to replace concrete labour) their would be (reservedly) no metabolism.[3]

In this understanding we conceive of societies, besides many other features, as systems extracting raw materials from their domestic nature (or buying materials form other socio-economies), subsequently transforming these materials within the economic process to provide material goods for domestic demand (and also for foreign demand). A number of materials stay within the socio-economy forming societies materials stock (like for instance buildings, roads, machines, etc.) whereas other materials are released to the domestic environment in the form of wastes and emissions rather immediately. In the view of metabolism, societies mainly have to face two problems, the ones of resource scarcity on the input side and the override of the absorbing capacity of domestic ecosystems on the output side.

Historically, problems of resource scarcity often have been addressed to technological advance where the argument was, that as long as enough energy is available resource scarcity problems always can be solved by technological solutions. Consequently, societal development and energetic resource use have been seen as linked for a considerably long time and also contributed to social theory formulation. The material aspect of societies metabolism appeared in the discussion more recently. Only in the 1970ies, when certain substances showed to be responsible for environmental pollution, substances and materials appeared in society's consciousness. Around 1990, alongside a paradigmatically shift in the environmental discourse the physical dimension of economic activities became more and more important. Subsequently, this inspires a number of conceptual works dealing with the industrial metabolism (Ayres 1994) and societies metabolism as a historical notion (Fischer-Kowalski and Haberl 1998). Nevertheless, apart from some exceptions, sociology as a discipline ignores the feedback's between the social realities and the material realities until today.[4]

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[2] This problem of the intentional structure of the labour process has been introduced by Ted Benton (1989) who argues, that Marxist tradition overestimates the transformative intentional structure of the labour process whilst not giving full credit to what Benton called the ecoregulatory labour process. This is exactly what Fischer-Kowalski and Haberl (1993) try to focus on by introducing the notion of colonisation of natural parameters. Colonisation of natural processes, like ecoregulation, refers to the deliberate and sustained transformation of natural processes using various forms of intervention such as planting, application of agrochemicals, consolidation of farmland, changes in water regimes, breeding or genetic engineering. See further explanation of this concept in Fischer Kowalski and Weisz (1999).

[3] It seems to be an open discussion, whether to refer to hunter and gatherer subsistence activities by the notion of work or not. Böhme (1984, 59) has argued, that labour only exists when a certain separation between man's relation to nature and his subsistence has already taken place. Following this argument the constitution of nature by human labour gains its historical explanatory power only after the Neolithic revolution.

[4] This argument is true for mainstream sociology, especially for the German speaking tradition. On the other hand, there is a strand of literature that straightforwardly addresses this issue of a realistic theory of society. Without having the space to fully acknowledge these renowned efforts we especially want to cite critical realism (Bhaskar 1998, Sayer 2000), Marxist ecology in-depth discussed in the Journal

THEORETICAL PRECONDITIONS FOR THE OPERATIONALIZATION OF THE NOTION OF SOCIETY'S METABOLISM[5]

The question raised here is what would theoretically be needed to follow the idea of society's production and reproduction by means of a natural resource background?

First of all it needs a concept of society that does not reduce society to a merely symbolic or cultural system of meanings and beliefs. As has been argued elsewhere (Catton and Dunlap 1978, Benton 1989, Fischer-Kowalski 1997), society also contains or consists of material elements further on addressed as the physical components of a socio-economic system.

Physical components of socio-economic systems

Following Marxist argumentation, we identify certain material elements to be physical components of a socio-economic system by using the concept of labour as a starting point. In this understanding, we consider every part of the material world that is produced by, or is periodically maintained by, human labour as being material components' of society. This argument of labour investment for maintenance is first of all true for humans (or human bodies). It also accounts for livestock and, even more widely shared, for the wide range of what we call artefacts. With the notion of artefacts, we try to subsume the whole man-made infrastructure, such as, for example buildings, roads, dams and sewers, machinery, vehicles, furniture and so forth. We argue that everything that is used by society for a period longer than a year should be considered as part of these physical components of society.

This implies that the complete metabolism of humans and of animal livestock has to be included in society's metabolism. It comprises nutrition, intake of oxygen and water, excretion, output of carbon dioxide and water, and also the deposition of dead bodies. One consequence of considering livestock as a physical component of the socio-economic system is that products from livestock like meat and milk, and so on are not treated as inputs from the environment into the socio-economic system. They have to be looked upon as transfers within the socio-economic system.

Theoretical considerations have been raised about whether to include plants as a component of the socio-economic system insofar as they are maintained by labour in agriculture and forestry. Here we suggest for pragmatic reasons that plants should not be considered as a component of the socio-economic system (Fischer-Kowalski 1997). Therefore, in the same way as they appear in agricultural statistics, plant harvest can be seen as an input to the socio-economic system whereas manure and fertilisers are an output to nature. If agricultural plants were considered as part of the socio-economic system, the boundary between this system and its natural environment would be pushed outward, to the mineral level, expect for fishing, hunting and gathering. Although there

Capitalism, Nature, Socialism (Benton 1989, Dickens 1992), and social geography (Harvey 1999). In my understanding, also ecological anthropology, science and technology and ecological economics can contribute to our understanding of society's interactions with nature.

[5] Arguments for this section stem from an Material Flow Accounting information package prepared by the IFF Social Ecology team in Vienna, used for knowledge transfer in research projcets (Marina Fischer-Kowalski et al. 1999). Information can be found at and downloaded from the IFF homepage http://www.univie.ac.at/iff.socec project section, Amazonia 21.

can also be reasonable arguments for the consideration of agricultural plants as part of society, this would not correspond to the economic logic of the SNA or to any economic statistics, which we consider as the most important criteria for policy relevance.[6]

Finally, we consider artefacts, the man-made and maintained technical structures as physical components of the socio economic system. This recognises powers of re-naturalisation, which are valid for all artefacts. Once society suspends further maintenance the process of naturalisation unavoidably starts and we not longer regard an object to be part of society's material components.[7]

According to convention two, all materials that serve to produce or reproduce (maintain) the physical compartments of the socio-economic system belong to its metabolism and therefore are counted as inputs res. outputs within material flow accounting. This draws our attention to the differentiation between stocks and flows.

Stocks and flows

Once these components are recognised (human bodies, livestock and artefacts) every material flow that produces or reproduces these components is considered to be an input to society's metabolism. These material flows are set in motion via society's activities to produce and maintain society's material stock (equating the material components). A reliable distinction between stocks and flows is a prerequisite for determining whether a socio-economic system is still growing in physical terms, is in a steady state, or is shrinking. This should refer to the size of the population, the size of the livestock and the weight of the artefacts (the infrastructure). Accordingly, an operational distinction between size and metabolic rate, between the growth rate and the energetic/material turnover of the socio-economic system can be drawn. Clearly, there is a close link between stocks and flows and also a positive feedback. The bigger the material stocks are, the bigger the future material flows needed to reproduce the material stock will be. This positive feedback can also be stated for future use of energy resources, labour investments, and monetary expenditures.

The law of "conservation of mass"

One basic idea of MFA should be the attempt to reach a full balance integrating the input and the output side. This idea of a mass balance is one of the most powerful features of the MFA approach. In terms of policy, this approach allows for the development of integrated resource and waste/emission strategies. Balancing is also a methodological tool, as it provides a framework for consistency checks and estimation of data gaps. For material balances the first law of thermodynamics, the "law of conservation of mass" applies, which is also a leading theoretical criterion for material

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[6] However, Stahmer et al. (1997) treated agricultural plants as component of the socio-economic system in their physical input-output analysis for the German economy for 1990. On the contrary, but alongside our own argumentation here, the physical input/output tables for Denmark treat agricultural harvest as input into the economy and livestock as being produced within the economy (Pedersen 1999).

[7] Undoubtedly, this idea could activate criticism regarding the correspondence of the introduced concept of 'belonging to a society' with other categories like property rights. We acknowledge here that this problem of correspondance has to be discussed in future research.

accounting. The law of conservation of mass attributed to MFA results in the following equation:

The sum of material inputs into a system = the sum of outputs corrected by changes in stocks.

This equation applies not only to the system as a whole but also to all its sub-systems to which we refer as components of the system.

The metabolism of the socio-economic system can be broken down into the metabolisms of its physical components. For each component, the law of conservation of mass applies.

This convention follows a systems approach that has so far been applied in a variety of disciplines. Biology, for example, conceives of an organism as an integrated entity, which is composed of interdependent components like organs or cells. Likewise, economics, especially in input/output analyses, conceives of a national economy as an integrated system composed of interdependent sectors. In both biology and economics the components or sectors are considered as entities which operate their own metabolism or input/output relationships respectively. According to this, we look at the metabolism of socio-economic systems as being composed of interdependent self-organising compartments that maintain their own metabolism, rather than being just an assembly of "material flows".

Due to the problem of double accounting, the sum of all material inputs and outputs of the components of a system does not equal the total material inputs and outputs of the system. The recently published physical input output table for Denmark (Pedersen 1999) discusses this for animal and vegetable products. The sum total of the weight of the intermediate consumption of these materials exceeds the amount of primary input to a large extent. This can be traced back to the disaggregation into compartments (sectors), as the metabolism of a compartment also records the processing of materials within the system. In highly functional differentiated economies, the output of one sector typically serves as input into others. Treating components as systems with their own metabolism emphasises, increasing with the degree of disaggregation, flows within the economy. The material interdependencies between the compartments/sectors of an economy become visible.

Water, air and "materials"

We distinguish between three main groups of input materials: water, air and all the other materials. The latter, the heterogeneous group of the non-air non-water fraction, consists of raw materials, semi-manufactured materials and final goods. Raw materials can further be differentiated into biomass, mineral materials and fossil materials. Such a differentiation is not appropriate for semi-manufactured materials and final goods as they appear as a material mix.

Water, air and materials should not be summed up. This has to do with the common-sense idea of not literally "drowning" economically valued raw materials and commodities in water and air.[8] However, this distinction does not hold up on closer examination, as the non-water non-air fraction is not free of water and air. Even worse, the content of water and air of the various materials changes due to natural processes (like evaporation, oxidation) and due to technical processes within the socio-economic system. Therefore, a consistent distinction between the three groups needs practical agreements. They are the following:

(a) Water and air that serve as a transport medium are reported as an important part of socio-economic metabolism but are not included in sum indicators like "direct materials input". (b) Inputs of the non-air-non-water fraction are counted, including water and air content, when they cross the border into the socio-economic system under investigation, that is usually when they are marketed. Therefore, all inputs are accounted for as market weights, with the important exception of timber, which is counted with standardised water content of 14%. (c) Water and air that become part of a material good during the production process are considered as part of the mass balance. These amounts of water are referred to as additional inputs of water and air. (d) Inputs that are not marketed like green fodder grazed by cattle are also accounted for with standardised water content of 14%.

Direct materials input and hidden flows (ecological rucksacks)

We defined all flows as input flows that pass through at least one of the physical compartments of the socio-economic system. Beyond these boundaries of the socio-economic system under investigation, material flows occur that do not pass through but are a prerequisite for the materials input of the socio-economic system concerned, even if they never cross its boundaries. These hidden flows or ecological rucksacks (Schmidt-Bleek 1994) might occur in the domestic natural environment or in the environment in foreign national economies. Therefore, one can distinguish between the hidden flows of imports and the hidden flows of domestic extraction.

Usually, these hidden flows comprise the material translocations, wastes and emissions that occurred in the production process of an imported good in the country of origin. Particular large material flows occur in domestic extraction (such as overburden in mining or eroded soil in agriculture). The way they are estimated, they tend to be at least as large as the direct materials input. The sum of direct materials input and hidden flows has been called "total material requirement (TMR)" (see Adriaanse et al. 1997). We, however, suggest it is better not to add up direct materials input and hidden flows, due to the weakness of data for the hidden flows and due to the incompatibility to SNA. In addition, one must take care not to add up TMRs of different socio-economic systems, neither as sums nor as per capita values, because of double counting.

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[8] A case study on Austria's economy wide Material Flow Analysis shows that water and air together account for 95% of the total weight of materials input (Schandl et al. 1999).

CRITERIA FOR MATERIAL FLOW ACCOUNTING[9]

Like any complex accounting system, MFA requires a guiding theoretical framework to ensure the consistency of the numerous decisions to be made. We refer to this as the criteria of **theoretical soundness**.

The guiding theoretical concept for explaining the physical interrelation of society and nature is *socio-economic metabolism* (see above), a concept applied to investigate the interactions between social and natural systems. It is the socio-economic metabolism (see Fischer-Kowalski 1997) that exerts pressures upon the environment. The socio-economic metabolism comprises the extraction of materials and energy, their transformation in the processes of production, consumption, and transport and their eventual release into the environment. Framed like this, MFA accounts for the overall material throughout, i.e. the overall metabolism, of a given socio-economic system. According to this concept we must have a systematic idea of the interaction of the two systems, society and nature and guidelines, of which elements of the material world belong to society and which to nature. That refers to a clear understanding and definition of the boundaries of the system under investigation. We will operationalize these requirements by applying systems theory and natural science considerations.

The usefulness of the MFA approach for informing sustainability strategies will also depend on how the linkage between environmental degradation and socio-economic activities is conceptualised. The mutual interrelationships between economic, political and environmental processes, available information, the judgement of experts and public awareness is highly complex. The criterion of **political relevance** refers to a well-chosen reduction of this complexity rather than to a full understanding. Policy relevance, then, refers to the strength of the concept to provide information for policy decision and public discourse. Therefore the information must be available relatively quickly and must successfully reduce complexity. Only if this is achieved, can MFA be a tool to operationalize the overall goal of future sustainability.

We propose the following sub-criteria: link to SNA, international comparability, indicating major trends in the ecological performance of societies, application for various levels of intervention, the possibility of time series and scenarios, and compatibility to established environmental information systems.

The application of these criteria would result in the conception of MFA as an umbrella environmental information system that is linked to the SNA, an approach that has sometimes been called “green accounting system”.

Finally, like any approach that addresses “real world problems”, the criteria of **feasibility** must be applied. This criterion refers to the availability of accurate data sets, which can be used for the MFA account. Further, MFA has to concentrate on a

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[9] The considerations for this section on criteria for MFA stem from a presentation made by Helga Weisz and Heinz Schandl at the Industrial Ecology Conference at Troyes, France (Weisz and Schandl 1999).

strictly top-down approach such as not to get lost in too many, though interesting, details.

METHODS FOR ACCOUNTING SOCIETIES METABOLISM

From a more technical point of view Material Flow Accounting can be broken down into different sub-accounts. We differentiate between the input side (input account) and the output side (output account) of the socio-economic metabolism. These two sides of accounting should be linked within a material balance. In bringing together inputs and outputs, the idea of a material balance focuses on the economic processes between inputs and outputs. Therefore, the material balance opens the black box of an economic system.[10]

Basically, we distinguish two empirical approaches. One approach is a full balance of inputs and outputs within an input-output framework for one year (usually in the near past). The other approach concentrates on time series for inputs and outputs but does not take the relation between them into account. Both approaches deserve different methodological treatment. The full balance for a year (material balance) should necessarily be based on an input/output accounting framework comparable to economic input/output tables (Weisz et al. 1999) and hence should take all available sources of evidence (like detailed case studies for certain sectors or materials) into account. Unlike this, a time series for inputs or outputs (material flow analysis) should restrict itself to periodically available data sets and should be reserved against data sources which are basically created for one specific point in time. Like material balances, time series analysis can largely profit from the insights gained by a full balance, due to cross checks that strengthen the accuracy of the data set.

This work provides only a small segment of MFA but concentrates rather on a relatively long time span. It reflects the input side for the economy of the United Kingdom (England, Wales, Scotland and Northern Ireland) for the period of 1937 to 1997.

On the input side we principally distinguish inputs of water, air and materials. As has been acknowledged earlier, the metabolism of an industrial society consists of 85% of water, about 8% of air and 7% all other materials (Schandl et al. 1999). The present data set for material inputs will ignore water and air. Hence, it will cover domestic extraction and harvest of materials and imported materials. These input categories will distinguish between biomass (agricultural harvest, timber harvest, fishing, hunting, collecting of wild vegetables, mushrooms and honey), mineral materials (ores, clay, industrial minerals, sand, gravel and crushed stone), and fossil materials (coal, natural gas, and crude oil). A fourth main category of input covers materials mainly manufactured as they appear via foreign trade. These materials are very often a mix of the above mentioned raw material categories and will, therefore, not be allocated to one of these categories (see Appendix 1, table of input categories).

The practicability of the data gathering process was guided by several main principles. First of all, we focussed on periodically available data supplied by official

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[10] Further considerations can be drawn from Weisz et al. (1999) which introduce a highly aggregated input/output table allowing for consistency checks and also for the derivation of physical environmental indicators. More importantly, the framework shows possibilities of linking different input factors like energy, materials and labour.

statistical bodies. We favoured these data collections which could already provide a certain level of aggregation. Most important here, of course, were the Annual Abstracts of Statistics, which offer an extensive data set to build upon. On the other hand, it was a methodological guideline not to extensively use case studies, which could provide an in-depth picture on a specific problem, but could by no means help to establish sufficient time series data. This was due to the fact that we wanted to end up with a summary aggregate, which will not change its magnitude permanently by embedding special knowledge of such, nevertheless important, case studies.

Besides the Annual Abstracts, the following main data sources were used:

- Agricultural Statistics
- Statistics on Supply and Demand for home-grown Timber in Great Britain provided by the Forestry Commission
- The British Geological Survey provided by the Natural Environment Research Council (United Kingdom Mineral Statistics)
- The Overseas Trade Statistics of the United Kingdom provided by the Department of Trade and Industry
- Input/Output Tables for the United Kingdom

SPECIFIC CHARACTERISTICS OF THE DATA SETS FOR THE DIFFERENT INPUT MATERIALS

Domestic extraction of biomass

Agricultural plant harvest constitutes the main inflow of biomass to the UK economy. This data is reported within Agricultural Statistics. A further concise data set is presented in the Annual Abstract of Statistics. It comprises crops, straw, fodder crops, vegetables, fruits, natural fibres and hay. Whereas all categories are available yearly for the period under investigation, this is not true for straw and hay.

Reported figures for straw end in 1977. Before that, crops and straw were reported independently for every different crop, which allows accounting for the harvest index for the period of 1937 to 1977.[11] From 1978 on we estimate straw harvest on the basis of known crop harvest by applying a linear extrapolation of the harvest index.

A similar estimate was undertaken for the harvest of hay, where figures also end in 1977. Again, we know the production of hay for the period of 1937 to 1977 and the related agricultural area. This allows accounting for the yield on grassland. Following linear trend prognosis for yields on known agricultural grasslands, estimates for hay production have been drawn.[12]

A second important inflow of domestic extracted biomass is timber. Here the situation is even more difficult, because, as far as could be investigated here, available statistical reporting lack accurate accounts for timber removes. Here we have built our estimates on different data sources. Numbers for the area of productive woodland, both public and private, are available for the whole period. This only gives a very rough background, since the area of productive woodland does not directly inform us about timber removals.

Annual Abstract of Statistics gives the volume of timber removed[13] for public and private woodlands for the period of 1976 to 1997. The forestry commission (1998) reports deliveries of home-grown timber[14] to wood processing industries for the period of 1977 to 1997 for Great Britain. These figures are based on processing industries' estimates of purchases of timber grown in Great Britain. Additional information was derived from the volume of home grown timber used in production, which is available for the period from 1940 to 1986 in the Annual Abstract of Statistics.

For this report, time constraints have meant that a less than satisfactory solution had to be found. From 1976, our report relies on the figures of timber removed from

[11] The harvest index is a measure which gives the proportion of crop to straw.

[12] In doing so, we follow a strategy suggested by Krausmann (2000), who established an excellent historical account on the socio-economic biomass metabolism in Austria 1830 to 1998.

[13] Reported data for timber in million cubic metres standing volume overbark. Cubic metres overbark are converted to cubic metres underbark by a conversion factor of 0.893 for softwood res. 0.875 for hardwood.

[14] Million cubic metres volume underbark. Cubic metres underbark are converted to cubic metres overbark by a conversion factor of 1.12 for softwood res. 1.143 for hardwood.

public and private woodlands. For previous years we had to estimate removals on the proportion of removals to home-grown timber for industrial use (not including use for paper production and other uses like fuel) as reported in the Annual Abstract. Unfortunately the overlap of both time series data was only for 11 years (1976 to 1986) where industrial use amounted for an average of 34,9% of total removals. As this also did not give a convincing picture we had to go for an assumption. We estimated timber removals as a function of home-grown timber used assuming the proportion of industrial use being 45% over the whole period, but being 75% in the war years of 1940 to 1943. Undoubtedly, timber removals will be an area of future investigation.[15]

Grazing of animals on grassland is another important inflow of biomass. Due to the fact that statistics only deal with marketed goods, these numbers are not available. We calculate the amount of grazed grass via the productivity of the areas for sole right rough grazing and common rough grazing.[16] Animal grazing is included to the biomass extraction aggregate with a standardised water content of 14%. This measure has gained international acceptance since other animal fodder also contains around 14% of water. The fact of large scale outdoor grazing should not lead to an incomparably high input by animal grazing compared to animals held in stable feeding.[17]

Another important inflow results from fishing. Here numbers are available for the whole period in the Annual Abstract of Statistics. Besides fishing, other inflows like plant biomass from wild harvest, hunted deer or honey should also be regarded as inflows. These flows, which are normally only very small compared to other inputs, are not investigated here.

Mineral materials

Inputs of minerals to the UK economy are available yearly in the United Kingdom’s Mineral Yearbook provided by the British Geological Survey for the whole period of investigation. These inputs cover iron ore, other ores, clay, gypsum and anhydrite, industrial minerals, salt, sand and gravel, and crushed stone (see Appendix 2).

This data set follows the run of mine concept and hence does not include the hugh amounts of removed materials, which are not considered to ever become part of economic activities such as overburden and translocations. These “hidden flows”, while not marketed, undoubtedly have an environmental impact and consequently their amount is of great interest within the sustainability debate (see Adriansee et al. 1997, Douglas and Lawson, submitted).

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[15] Interestingly, well-known publications, such as for instance Mitchell (1988), do not report on domestic timber removed at all. Though this finding supports our argument of lacking data, it certainly does not satisfy our efforts to end up with accurate figures on socio-economic metabolism.

[16] Again this is a methodological solution suggested by Krausmann (2000).

[17] To strengthen the reliability of data for animal grazing, a future account should be established on an input/output belance of the metabolism of livestock.

In this study we concentrate on direct flows and hence do not report the hidden flows.

Whereas data accuracy is traditionally good in Mineral Statistics, this is, as experience shows, not true in the same way for the mass minerals (sand and gravel, and crushed stone). These aggregates are often underestimated in official statistics, for several reasons. (a) Minerals are extracted via an owner's property right; (b) minerals are extracted within a company, which directly uses these minerals, for instance for concrete production. Therefore only the amount of concrete is reported in production statistics but not the amount of minerals extracted; (c) mass minerals are usually cheap and hence not an important input factor in economic calculation. Estimates might be rather rough. For such reasons the actual input of mass minerals often overrides official numbers by far (see Schandl et al. 2000).

Though an in-depth investigation on this problem would overextend the capacities of this study, we should very briefly discuss the reliability of official data. Concerning the development of domestic extraction figures, these seem to reflect the economic development in the construction sector, where numbers of new buildings and of new road kilometres went down accordingly. This is supported by the fact that reconstruction work is comparatively high in UK compared to other European countries (see Social Trends). Therefore, we suggest trust in the development but not in the absolute level of domestic extraction of mass minerals. We will come back to this point later on, when we discuss the UK final figures compared to other industrial economies within the notion of a characteristic metabolic profile of industrialised economies.

Fossil materials

As for minerals, the inputs of domestic extracted fossil materials (coal, crude oil and natural gas) to the UK economy are available yearly in the United Kingdoms Mineral Yearbook. These data are very reliable because energy has been a main issue of statistical reporting for decades.

Imported and exported materials

Foreign trade is responsible for the second type of input to an economic system. Differently from domestic extracted materials, imported materials are not only raw materials, although they are largely so. Besides raw materials, input consists of semi-manufactured or final goods, which reflect the international distribution of labour. Foreign Trade Statistics provide accurate and detailed data, which clearly is not organised in the way a material flow account requires. The main problem is the fact that on the level of aggregation necessary for MFA, no comprehensive physical data is available. For the period of 1937 to 1973, our study builds on the Annual Abstract of Statistics reporting for main imported and exported products. These are available in physical units, not always in tons but sometimes m^3, m^2, numbers or pairs. In early years many positions are reported in empirial units. Although reported numbers had to be converted to metric tons, which was not always easy such as for pairs of shoes or socks, this data set proved to be useful.

For the period from 1973 on, we had to choose another strategy that did not prevent us from doing full accounts for some years between 1973 and 1997. The full account for 1973 also served to test the proportion of imports/exports covered by the Annual Abstract list of main products. These actually cover 95% of total imports/exports. Full accounts where also done for the years 1980, 1985, 1991 and 1997. Intermediate years were estimated on the basis of economic import/export data available in the Annual Abstract since 1974 by using a £/tons conversion factor from the years of detailed investigation.

Imports and exports for fossil fuels are based on actual data from Foreign Trade Statistics for all years.

EMPIRICAL RESULTS FOR THE UNITED KINGDOM

Looking at the physical dimension of the UK economy within the last decades clearly shows that material input had come, after a period of rapid growth from the 1940ies to the 1970's, to a standstill. In the 1940's, average DMI accounted for 413 million tons (or 8.5 tons per capita). The Fordist compromise between capital and labour led to a new regime of accumulation and went hand in hand with a specific metabolic regime characterised mainly by rapid growth of yearly inputs of minerals and fossil fuels. This results in a growth of overall material input from an average of 413 million tons in the 1940's to an average of 774 million tons in the 1970's. While minerals and fossils input massively grew (140% growth for minerals res. 46% growth for fossils between the 1940's and the 1970's), biomass input remains more or less stable (only 18% growth between the 1940's and the 1970's). Imports show a different pattern and seem to be more vulnerable to change than other inputs (see Table 1).

Table 1. Yearly average materials input to the UK economy for the last decades, in million tons

	1940's	1950's	1960's	1970's	1980's	1990's
Biomass	79.6	84.5	89.5	91.9	95.1	97.7
Minerals	115.0	194.9	300.5	361.5	318.4	317.1
Fossils	203.3	261.1	270.6	304.3	326.8	311.3
Products	15.6	6.2	9.6	16.3	32.2	51.0
Direct Material input (DMI)	413.4	546.7	670.2	774.0	772.5	777.2

In the 70's there must have been a turning point both in the economic regime and subsequently also in the metabolic regime. First of all, overall growth came to a standstill. The UK economy has stabilised the material inputs at a high level. Nevertheless, different aggregates show a different trend. While fossil fuels and imported products still contributed to growth, there had been a comparably sharp decline in mineral materials especially from the 1970's to the 1980's.

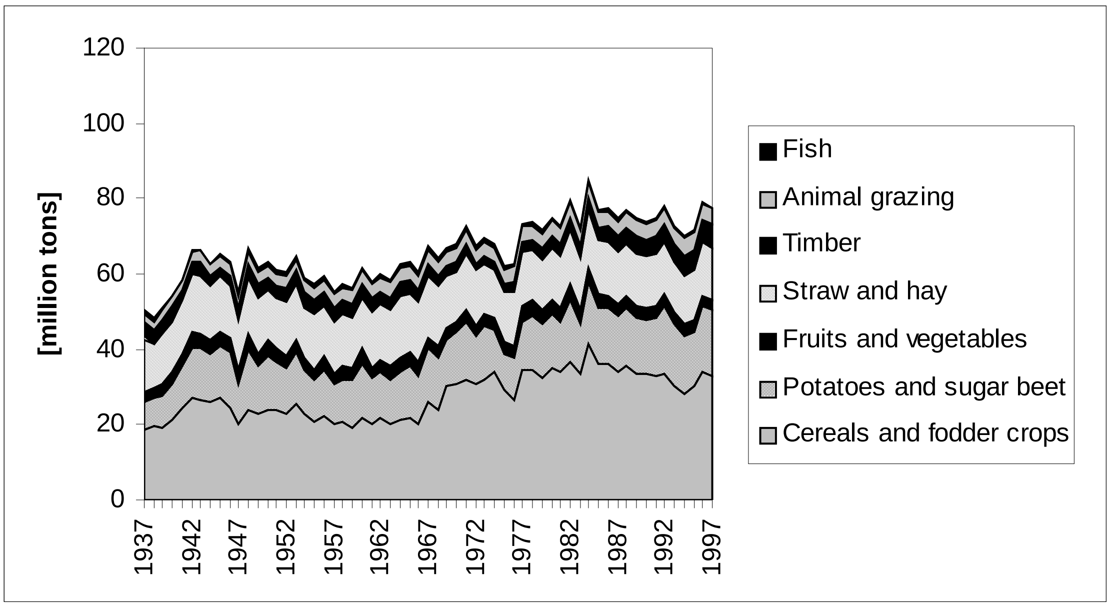
At the same time biomass input to the UK economy remained a more or less stable fraction of socio-economic metabolism, though growing rates also point downwards (see Table 2).

Table 2. Relative change of average materials input in the UK, percentage

	Average 1940 to average 1950	Average 1950 to average 1960	Average 1960 to average 1970	Average 1970 to average 1980	Average 1980 to average 1990
Biomass	6.2 %	6.0 %	2.7 %	3.4 %	2.8 %
Minerals	69.5 %	54.2 %	20.3 %	-11.9 %	-0.4 %
Fossils	28.4 %	3.6 %	12.5 %	7.4 %	-4.7 %
Products	-60.0 %	54.2 %	68.9 %	98.4 %	58.3 %
Direct Material Input (DMI)	32.2 %	22.6 %	15.5 %	-0.2 %	0.6 %

What follows is a brief, more detailed, description of the different input aggregates, starting with domestic extraction of biomass. As we have shown, biomass extraction is the most stable part of the UK metabolism. A closer look shows that crop harvest has particularly undergone considerable change. The amount of harvested cereals and fodder crops was never above 25 million tons per year. Since the early 1960's, when due to the final step in the industrialisation of agriculture the level of crop harvest could be increased to about 32 million tons (even short-time yearly harvest of over 35 million tons appears during the 1980's). These gains of efficiency on agricultural cropland did not occur in the same manner for other agricultural products. Straw and hay always remained stable at around 14 million tons per year and did not reflect the increase for crops, which is mainly due to the strategy for increasing the proportion of crop of the plants. Potatoes and sugar beet went from an average of 8 million tons before the war to an average of about 14 million tons after 1945. The harvest then remained more or less stable between 12 to 14 million tons yearly, to show a final upward trend only recently up to 16.7 million tons between 1995 and 1997 (see Figure 1).

Figure 1. Domestic extraction of biomass in the UK for the period of 1937 to 1997, in million tons



Fruits and vegetables always contributed to the biomass extraction by a yearly average of 3 to 4 million tons. Since the late 1970's, there is a clear downward trend to the current 3 million tons. The fish catch contributed by around 1 million ton yearly before around 1975 with a sharp decline during wartime. From 1975 on we can observe decreasing catch rates with currently 0.5 million tons.

Animal grazing amounts for 2.4 million tons in 1937 and grew within the next 25 years to 3.8 million tons. From then on, the growth rate flattened until 1980-84 at a level of around 4 million tons but increased again to a level of 4.4 million tons in 1985-89. This also reflects the development in the number of livestock, cows and sheeps, in the UK (see Appendix 5, Figure 8).

Figures for timber are still to preliminary too give a valid comment. It is safe to say that since 1970-74 timber removals from UK woodlands steadily increased from 2.1 million tons to the current 5.8 million tons. This is also due to land use change in the UK since 1937, when woodland only accounted for 5.1% of total area. The proportion of woodland could, due to forestation efforts, be increased to 10.9% of total area nowadays. What nevertheless has to be recognised is the mix of trees, with a large proportion of Conifers (82% of all woodland) and the subsequent trend to monocultures.

The domestic extraction of mineral materials gives evidence to a different story since it is more closely related to the production side of the UK economy than is the biomass extraction.

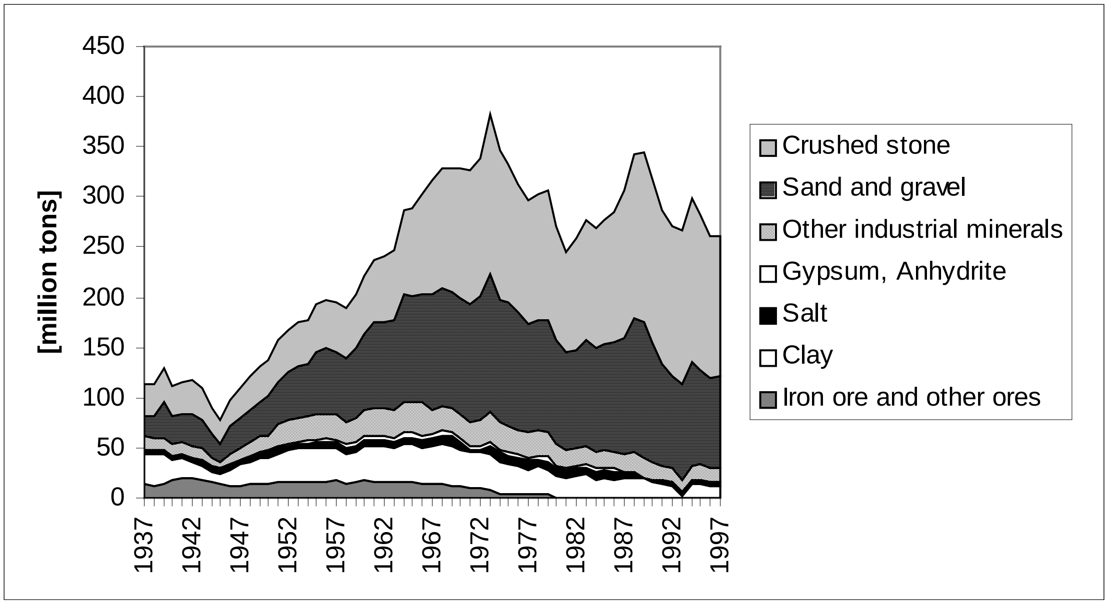
Iron ore and other ore extraction is closely linked to the industrial-military production process. Hence, ore extraction did not show the typical decline or at least stagnation during the war. The period 1940-44 showed the highest ore extraction ever, which lies at 18.1 million tons. Before that, ores contributed with 12.7 million tons, and after with 12.8 million tons to domestic mineral extraction. Mining of ores in the UK increased until 1960-64 (16.3 million tons) and faced strong decline from the on. It was in the period of 1980-85 when the UK ore mining industry was closed down, with only around 0.6 million tons ores extraction yearly.

Clay extraction, due to the production of bricks, was traditionally high in the UK and was around 30 million tons before the war. Declines during the war took the clay extraction industry a decade to recover. In the early 1950's, clay extraction reached the level of before the war and went up to around 40 million tons until 1970. From then on follows a period of sharp decline, around 26.5 million tons of clay between 1980-84 and around 20.9 million tons between 1985-1989. Currently, 1995-97 clay extraction accounts for 12.9 million tons.

The aggregate of minerals for industrial use behaves similar to clay. Starting at around 11.7 million tons after the war, they reached a high of 27.6 million tons between 1965-69. What followed was a 15 years period of moderate decline and then two decades of sharp decline, from the late 1970's on. Currently, industrial mineral extraction lies at around 14.7 million tons. More or less the same trend is followed by gypsum and anhydrite as well as salt extraction, even though at a lower level.

Mass minerals mainly used in construction activities like sand, gravel and crushed stone tell a similar story. Starting at a level of 30 million tons before and during the war, the domestic extraction of construction minerals grew explosively within a period of 30 years to reach 140 million tons of crushed stone and 120 million tons of sand and gravel around 1975, 4 times above the original level. What followed was a decade of sharp decline up to 1985 followed by a short phase of resurgence, when both aggregates reached the level of 1975 in the period 1985-90. From then on, extraction of crushed stone and of sand and gravel, which were always linked before, delinked. Crushed stone stabilised around 145 million tons yearly whereas sand and gravel extraction has recently gone down to around 95 million tons (see Figure 2).

Figure 2. Domestic extraction of mineral materials in the UK for the period of 1937 to 1997, in million tons

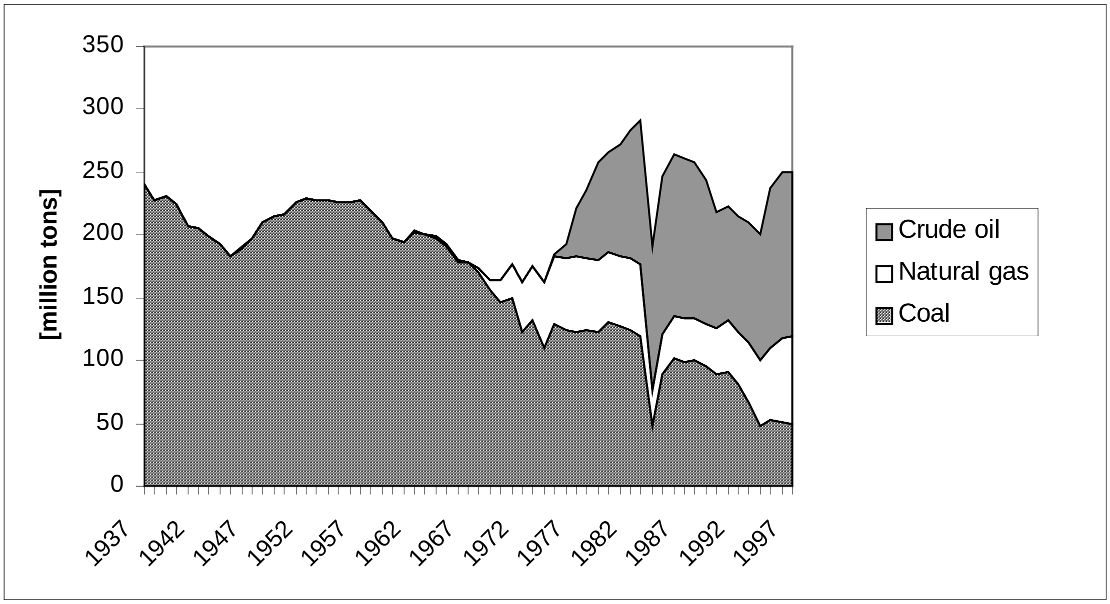


Fossil fuels extraction is a dominant feature of the UK extraction industry. Here we distinguish between two phases, the coal regime and the regime when natural gas and shortly after crude oil started to play a major role and finally replaced coal. Coal extraction was at around 240 million tons in the mid 1930's. It went down slightly during the war and recovered in the period 1950-54, reaching again around 230 million tons yearly extraction.

What followed was a journey on a roller coaster. Starting between 1955-59 the decent began, somewhat cushioned since 1970-74 but steady. Currently, coal extraction amounts to 50 million tons per year. Clearly, coal extraction declined before domestic extraction of natural gas and crude oil became an important factor in the UK extraction industry. Natural gas started in 1968, crude oil extraction had its break through in 1976, shortly after the first, undoubtedly politically motivated, oil crisis.

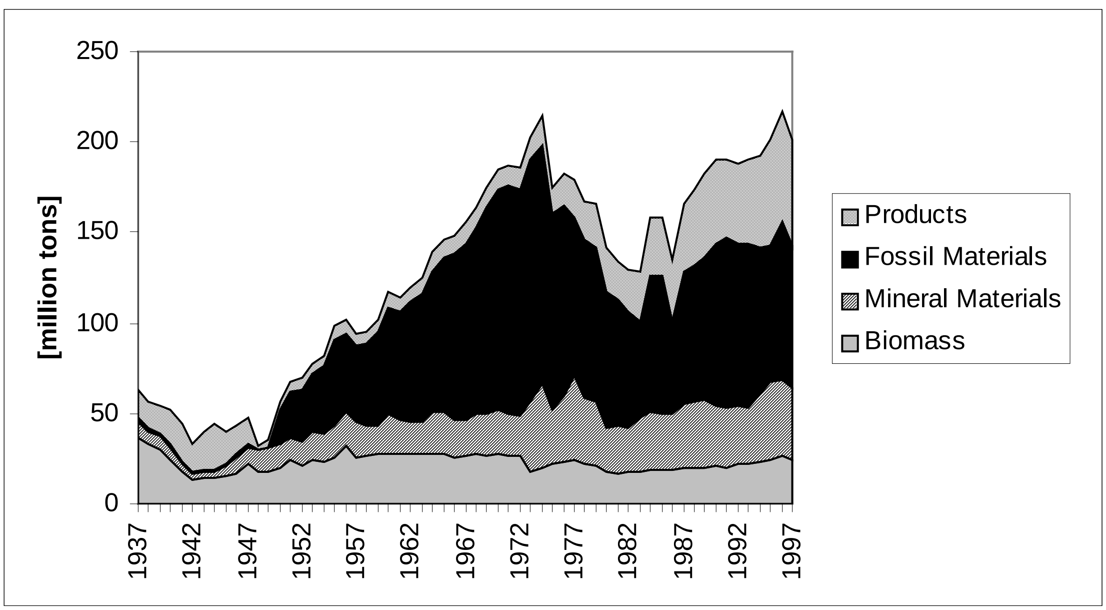
The overall picture of domestic fossil fuels extraction began to take off in 1975, which lasted until 1983. 1984 shows a sharp decline due to the miners' strikes. Although extraction went up again, the late 1980's and also the early 1990's were periods of decline, with a lowest extraction in 1994 of 201 million tons. Currently, 1997, domestic extraction of fossil fuels lies at 249 million tons (see Figure 3).

Figure 3. Domestic extraction of fossil materials in the UK for the period of 1937 to 1997, in million tons



Not surprisingly, fossil fuels are also the main aggregate of imports and exports. Imports of fossil fuels became relevant after the war and reached a peak between 1970-74, when around 130 million tons of fossils were imported yearly. Up to this point, fossils also made a dominant contribution to the UK exports, mainly as coal. This changed when the UK gas and oil industry started. Since then, around 1975, imports of fossils decreased considerably whilst exports almost exploded (see Figure 4 and 5).

Figure 4. Imported materials to the UK economy for the period of 1937 to 1997, in million tons



Imported biomass amounted to around 30 million tons before the war and to around 20 million tons during the war. In 1960-64 biomass imports again reached a level of 27.7 million tons but began a decline for the two following decades with only

17.7 million tons in 1980-84. Since then a phase of growth has taken place with a current 25.3 million tons of biomass input.

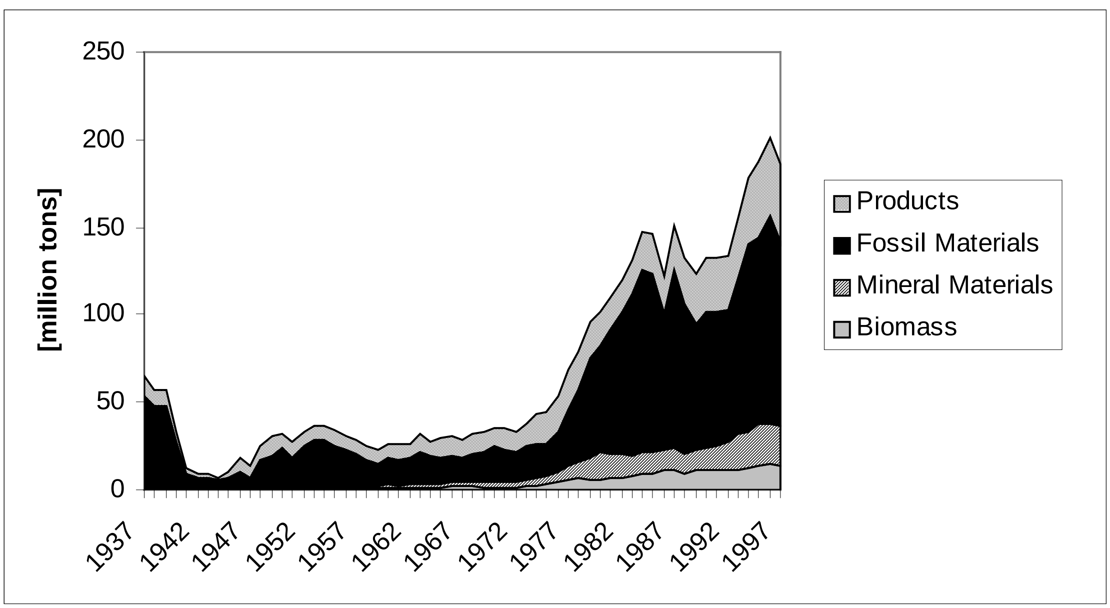
Imported mineral raw materials were not very important quantitatively before (7.7 million tons) and also not during the war (4.3 million tons). This was followed by a phase of steep linear growth up to 37.1 million tons in 1975-79. Since that period it was only in 1980-84 that imported minerals went down in the short-term to 27.5 million tons. Currently, they have reached a peak at 41.1 million tons.

The segment of imported semi final or final products both for intermediate use and final consumption were at around 20.5 million tons during the war but went down to 5.4 million tons within the next decade. Since then they followed exponential growth with today's 59.3 million tons of imported products (see Figure 4).

Second most important, beyond fossil fuels, within UK exports are semi final and final products. They contributed 9.7 million tons before the war and 2.9 million tons during the war to UK exports. From then on, they showed exponential growth rates facing only one short-term cut in the period 1980-84. They have reached a current peak of 44.1 million tons.

Exports of mineral and biomass raw materials only became quantitatively important after 1970-74. From there, biomass went steadily up to its current 14.2 million tons mainly due to crops export, whereas minerals went up to its current 22.9 million tons. Mineral exports, highly inflated by sand and gravel from new coastal pits, faced a short-term interruption of growth in 1985-89, which led to a new growth phase (see Figure 5).

Figure 5. Exported materials from th UK economy for the period of 1937 to 1997, in million tons



If, since 1937, the UK has been, monetarily speaking, an economy showing a positive balance of trade the same was not reflected in the physical balance of trade. From 1939 to 1947, imports were about 30 million tons above exports to catch up with imports in 1948. Since 1949, imports grew quickly to a peak of 214 million tons in 1976 whereas exports stabilised around 40 million tons. Since 1976, imports have declined and exports, at the same time, faced steep growth catching up with imports again at a level of 130 million tons in 1983. For some years imports and exports went jointly together at the same level, when imports started to override exports again between 1988 and 1994. Within the last 3 years, imports were only insignificantly above exports, but following exactly the same trend. Both imports and exports reached their highest level ever in 1997 with 217 million tons of imports respectively 201 million tons of exports (see Appendix 5, Figure 7).

So far we have only discussed developments in material input, restricting ourselves to descriptive statements. Nevertheless, it might be important to gain a certain understanding of what the relation of materials input to other macroeconomic parameters might be. Keeping in mind that this paper's main issue was to develop and present a method and a data set following from these, we want to give a brief idea of the relation of direct material input to population and economic growth.

Table 3. DMI per capita, GDP and Population in the United Kingdom during the last decades

	1940's	1950's	1960's	1970's	1980's	1990's
Direct Material Input (DMI), tons per capita	8.42	10.73	12.42	13.87	13.63	13.33
Real GDP, £ billion[18]		267.71	358.77	466.01	562.23	551.30
Population, millions	49.07	50.99	53.97	55.80	56.69	58.30

At first sight, overall GDP seems to explain developments in direct material input, whereas population, being a rather stable factor, plays only a minor role. With regard to GDP growth rates over the decades slowed down; from the 1980's to the 1990's there was no economic growth at all. It seems that the post war institutional growth constellation was no longer available in the 1980's and subsequently economic growth came to a standstill which also affected the material regime (see Tables 3 and 4). On the other hand, population growth is a feature of the industrial society often underestimated. After all, the UK population grew from an average of 49 million in the 1940's to a current average of 58 million, in other words by 25%. Different from GDP and DMI, there has not been a comparably sharp decline since the 1980's. Clearly, further investigations are necessary to gain an in-depth picture of the relation of economic variables, distribution variables and material flows.[19]

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[18] Corrected GDP at constant 1995 prices.

[19] Correlation analysis documents a stronger relation between population and materials input (r = 0.961**) than between GDP and materials input (r = 0.853**). This result indicates that developments in materials input might be explained by GDP or population. Further analysis should rely on regression analysis and t-test and should also test the variables for unit roots.

Table 4. Relative change in DMI per capita, GDP and Population in the United Kingdom during the last decades

	Average 1940 to average 1950	Average 1950 to average 1960	Average 1960 to average 1970	Average 1970 to average 1980	Average 1980 to average 1990
Direct Material Input (DMI) per capita	27.4%	15.8%	11.7%	-1.8%	-2.2%
Real GDP		34.0%	29.9%	20.6%	-1.9%
Population	3.9%	5.9%	3.4%	1.6%	2.8%

More recently, the Environmental Kuznets Curves (EKC) framework has been introduced to analyze the linkage between the economy in monetary terms (i.e. as measured by economic indicators as for example GDP or GNP) and the associated physical flows. EKCs are constructed by explicitly relating per capita income (GDP or GNP per capita) to environmental indicators in the broadest sense (World Bank 1992, Selden and Song 1994, Shafik 1994, de Bruyn and Opschoor 1997).[20] EKCs thus allow a conceptual separation of "economic growth" in monetary terms from "physical growth" in terms of tons and joules and hence to empirically assess how these two dimensions of the economy are related. The underlying idea, or hope, expressed in EKCs is that it could be possible to achieve an environmentally sustainable economic growth by fostering monetary growth while at the same time reducing the physical flows associated with it.

EKC may have an "inverted U shape" or a "N shape". The inverted U shape indicates a de-linking of environmental pressures and per capita income, while the N shape hints at the possibility that a period of de-linking may be followed by a phase of re-linking of physical flows and economic growth. De-linking may be envisaged as a result of technological change and/or changes in prevailing production patterns due to various reasons, and/or changes in environmental policy. However, delinking may not be a stable and persistent process due to the fact that efficiency gains might be of short duration. In the long run a re-linking of GDP and material input may take place. In this case the EKC will be shaped like a "N" instead like an inverted "U".

Early empirical work within the EKC framework, mainly conducted by economists, tended to relate all environmental data at hand with GDP values, regardless whether they indicated pressures, natural states, or feedbacks of environmental change on society. These indicators included among others indicators for lack of safe drinking water, lack of urban sanitation, annual deforestation, dissolved oxygen in rivers, fecal coliforms in rivers, ambient SO_2 levels, municipal waste per capita, and carbon emissions per capita (e.g. Shafik 1994). Not surprisingly, indicators for problems ready to be solved by technical solutions such as for instance end of pipe technologies could be quite easily de-linked from GDP growth, whereas overall resource use indicators, e.g. carbon emissions, tended to be linked much more

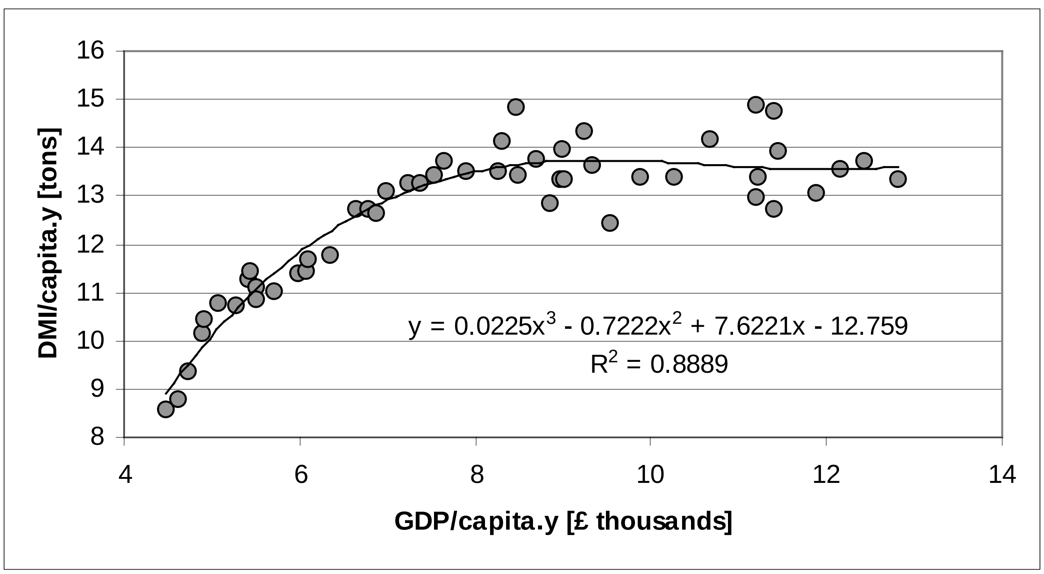
[20] A comprehensive disccussion of the Environmental Kuznets Curves research can be found in a special issue of Ecological Economics (Vol. 25, No. 2, 1998).

closely to economic activity. Here we shall argue in favor of a more systematic approach, i.e. an approach which only links indicators for driving forces with indicators for pressures, but not directly with indicators for natural states or effects of environmental change on society. This appears necessary for constructing theoretically plausible models.

Recent empirical EKC case studies also offer a more stringent approach by using indicators for total material throughput, energy use, or large material flows such as for example CO_2 emissions. De Bruyn and Opschoor (1997) suggested examining the hypothesis of delinking effects in industrialized societies using data for total material throughput. As there were only limited data available on this, they used the data from Jänicke et al. (1989) who provide four types of proxies for total material throughput: energy consumption, steel consumption, cement production and weight of freight transport on rail and road. Following a concept of indicators rather than total flows, de Bruyn and Opschoor consider these proxies as a reliable set of data, which captures to a large extent the environmentally relevant part of industrial metabolism. Taking into account the latest empirical works the EKC discussion could refer to complete MFA data like the data set presented here.

Basically EKC do not represent a time series. Due to the fact, however, that industrialized economies have growing GDP rates almost throughout the time period, the GDP scale implicitly covers the time scale. For this reason we may in this particular case interpret the EKC also according to the time dimension.

Figure 6. A Kuznet Curve for the UK economy



At low GDP rates between 4 thousand to 8 thousand £ per capita yearly material input undergoes constant growth from 8.5 tons to 13.5 tons per capita yearly. From then on it seems that GDP rates between 8 thousand £ up to 13 thousand £ per capita went hand in hand with material input at a range of between 13 to 15 tons per capita. This picture supports the underlying idea of the inverted U shape of the Kuznet Curve that, from a certain point on, growing affluence might be achieved with less exploitation of natural resources. This, in the case of the UK, might rather be a story of structural change and to a less extent technological advancement than of a successful environmental policy. This argument is supported by the fact that, since the 1980's, extraction industries and other traditional industries closed down and the UK economy underwent a considerable transformation from a merely industrial economy to a service economy (see several articles in New Left Review during this period). This probably had a positive side effect for the environmental performance of the UK with respect to resource use.

THE CHARACTERISTIC METABOLIC PROFILE OF INDUSTRIAL SOCIETIES

Since the early 1990's, a number of empirical case studies estimating the resource basis of industrial economies were developed. Based on these case studies, the characteristics of industrial metabolism can be portrayed. One obvious feature of industrial metabolism is the enormous amount of throughput. This is true in the historical comparison with agricultural societies but also compared to recent industrial societies and societies in transition. The level of use depends on the way basic needs are met. At a closer look, the high level of use appears to be a result of construction intensity, nutrition habits, energy supply sand the organisation of mobility where industrial societies show a preference for material intensive supply systems. The amount of consumer goods plays a comparably less important role, even though we have to bear in mind, that a great amount of resources, both materials and energy, are mobilised to produce them.[21] Nevertheless, the dimensions of the material relations have changed dramatically. The metabolic profile of industrial societies is dominated by a small number of materials; for instance water accounts for around 87% of yearly throughputs. Air is in the magnitude of 8% whereas all the other materials (biomass, minerals, fossils and imported products) only amount for around 5% (Schandl et al. 1999). Also here some materials dominate the total aggregate like mineral mass materials (sand, gravel, crushed stone and rocks), fossil fuels, wood and feeding stuff for animals.

A second new feature is the growth dynamic, which is different from the agrarian mode of production not only quantitatively but also qualitatively. Whereas in agrarian societies innovations constantly came to a standstill at the limit established by the solar energy system, industrial society seems to posses limitless energetic resources.

A further feature is the low capacity of recycling. Currently, less then 10% of yearly throughput (of course not including water and air) are kept within the recycling loops.

It has even to be doubted that the recycling potential can be raised remarkably due to the fact that a serious amount of materials cannot be recycled at all.

As has been argued before, industrial economies tend to use materials for a certain time period. These materials make up society's material components or, in other words, the material stocks. Due to mainly construction activities, means of production, and durable consumer goods net addition to stocks are relatively high and amount to between 5 and 11.5 tons per capita and year. Having in mind the feedback relationship between stocks and flows described earlier in this paper one can easily have an idea of future self-commitments of industrial societies.

Another important feature of the metabolic profile of industrial society is the over-use of air as a sink. The main output category of disposals to domestic nature is CO_2

[21] We should bear in mind the amount of physical advance achievments necessary to make available the production infrastructure. In addition all payments due to the transport infrastruvcture to distribute final goods and the whole comerce infrastructure.

caused by fossil fuel use, animal keeping and waste incineration. Industrial societies were environmentally successful in cleaning up the waters in the 1960's and by reducing local toxic air emissions by introducing end of pipe technologies. Currently, the problem of increasing waste amounts is met by waste incineration resulting in a problem shift from one gateway to another, from the soil to the air. Since outputs like CO_2 cannot be reduced by aftercare technologies environmental problems shift from the local to the global level. To date it is not obvious who the political actors, who will be able to cope with this global scale problems, might be.

The remarkable similarities of societies metabolism in industrial economies encourage us to talk about a characteristic metabolic profile. Looking at the sheer level of average consumption it amounts to 18 tons per inhabitant and year (see table 5). It should be further analysed and discussed if there appears to be a different pattern within different groups of economies. On the one hand, there are Austria, Germany and the USA with a shared average of around 19 tons and on the other hand, there are Japan and the Netherlands with an average of around 16 tons.

Table 5. A comparison of the materal consumption in several industrial economies, in tons per capita for the year 1991

	Austria	Germany	Japan	Netherlands	USA	M[22]	UK
Biomass	4.8	2.6	1.5	4.3	3.0	2.9	1.5
Minerals	10.6	10.7	11.8	5.9	8.0	8.7	5.3
Fossils	3.0	6.2	3.3	6.4	7.7	5.1	4.2
Products	0.1						0.2
Domestic material consumption	18.5	19.5	16.6	16.6	18.7	16.8	11.1
Population (in millions)	(7.8)	(80.0)	(124.0)	(15.0)	(252.8)		(57.8)

Source: Adriaanse et al. (1997) on Germany, Japan, the Netherlands, and USA , Schandl et al. (2000) on Austria, own calculations for the UK

Data for the UK economy in this table seems to be an outlier in this shared picture. This might be the case for two reasons; first, the accuracy of the available statistical data, especially true for construction materials, is still weak. Looking at the numbers we consider biomass consumption and fossil fuels consumption data to be very reliable. Mineral consumption is significantly low but on the other hand in a range with the Netherlands experience. Undoubtedly, the Netherlands is closest to the UK with regard to geomorphological features. Even if minerals consumption for the UK were to lie at around 6 to 7 tons, there seems to be slight evidence that the UK economy would follow a different pattern. What could speak in favour of this idea of a new pattern? One argument might be that the UK, as the entrepreneur of industrialisation, has taken another historical path than that of late industrialisers. Due

[22] Unweighted arithmetical mean.

to this, the UK economy has closed the old extractive industry of coal and iron mining. Further, the UK economy, for a rather long time period was not privileged by an oversupply of domestic resources. It might also contribute to the overall picture that the UK economy was transformed in the 1980's due to political decisions of the government in those days.

In any case the metabolic profile of the industrial mode of production differs clearly from metabolic profiles of other modes of production. In comparison to agricultural societies, industrial societies mobilise four times as much material resource than the former. In doing so, they rely to a much higher degree on non-renewable resources.

Some current research results can shed light on these metabolic differences between different modes of production. The yearly materials consumption of an industrial society amounts to 18 tons per capita, the one of agricultural societies typically to 4 tons per capita, whereas hunters and gatherers only mobilise one ton per capita and year. Energy use shows a similar and more dramatic picture. The yearly per capita use of an industrial inhabitant amounts to an average of 250 GJ (10^{12} J), of an agricultural inhabitant of 65 GJ and of a hunter and gatherer 10 - 20 GJ (Fischer-Kowalski and Haberl 1998).

These results point to an conclusion, that a specific mode of production and a specific regime of capitalist accumulation also introduce a specific metabolic regime.

CONCLUSION AND OUTLOOK

The main aim of this work was to introduce the methodology for physical accounting and to establish an initial data set for the input side of material flows into the UK economy. For the first time a comprehensive data set for the material inputs for the past six decades (time series 1937 – 1997) is now available. Therefore, this study offers unique insights, because empirical work on historical material flows is still rare.[23] Due to the fact that this has already been enormously time consuming, we restricted ourselves to the descriptive. Nevertheless, we know that further analysis and interpretation would be necessary to gain a more fundamental understanding of the physical background, as well as of the interrelationship between physical parameters and other socio-economic parameters, of the United Kingdoms' economic development for the time period under consideration.

Moreover, improvements of the data set are possible and necessary. While parts of the data set are already accurate, other parts are still weak. This is particularly true of data for the domestic extraction of mineral materials and for timber removals. Notwithstanding, our experience tells us, that this might change the level of total inputs but will not affect the underlying trend.

We have seen that the phase of rapid growth of the UK physical economy is definitely over. Though there has been a peak in materials consumption around 1990, the growth dynamics clearly stopped in the 1980's. Whether this establishes a stabilisation of materials use on a high level and supports the, at the moment rather speculative, thesis, that the UK economy represents a new post-industrialised metabolic pattern, has to be backed up through further investigation.

Undoubtedly also, the argument for a connection between material flows and environmental degradation as well as between socio-economic driving forces and material flows has to be strengthened in future research attempts.

There are mainly three strands we will follow in future research. Firstly, we will follow the idea of a historical understanding of society's metabolism by looking back in history. Hence, we will go back to the 1860's with the time series for material inputs. Secondly, we will place the analysis of society's metabolism in a broader concept of a physical economy. To do this, we will link the analysis of society's metabolism to an analysis of the labour process. This can contribute to a co-evolutionary theory of society-nature dialectics. Thirdly, we will develop a research proposal for a feasibility study for an integrated material balance for the UK economy for one of the recent years.

It is this attempt to establish a material balance for the UK economy for a recent year, which can contribute to the sustainability discussion and to the development of integrated physical environmental indicators for the UK. This contribution of MFA to the political discussion we consider as most important, since social science, especially public funded research, has to gain some added value for society as a whole.

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[23] Empirical research usualy starts only in the 1970's. Among the exeptions Krausmann (2000) on biomass metabolism for Austria (1830-1998).

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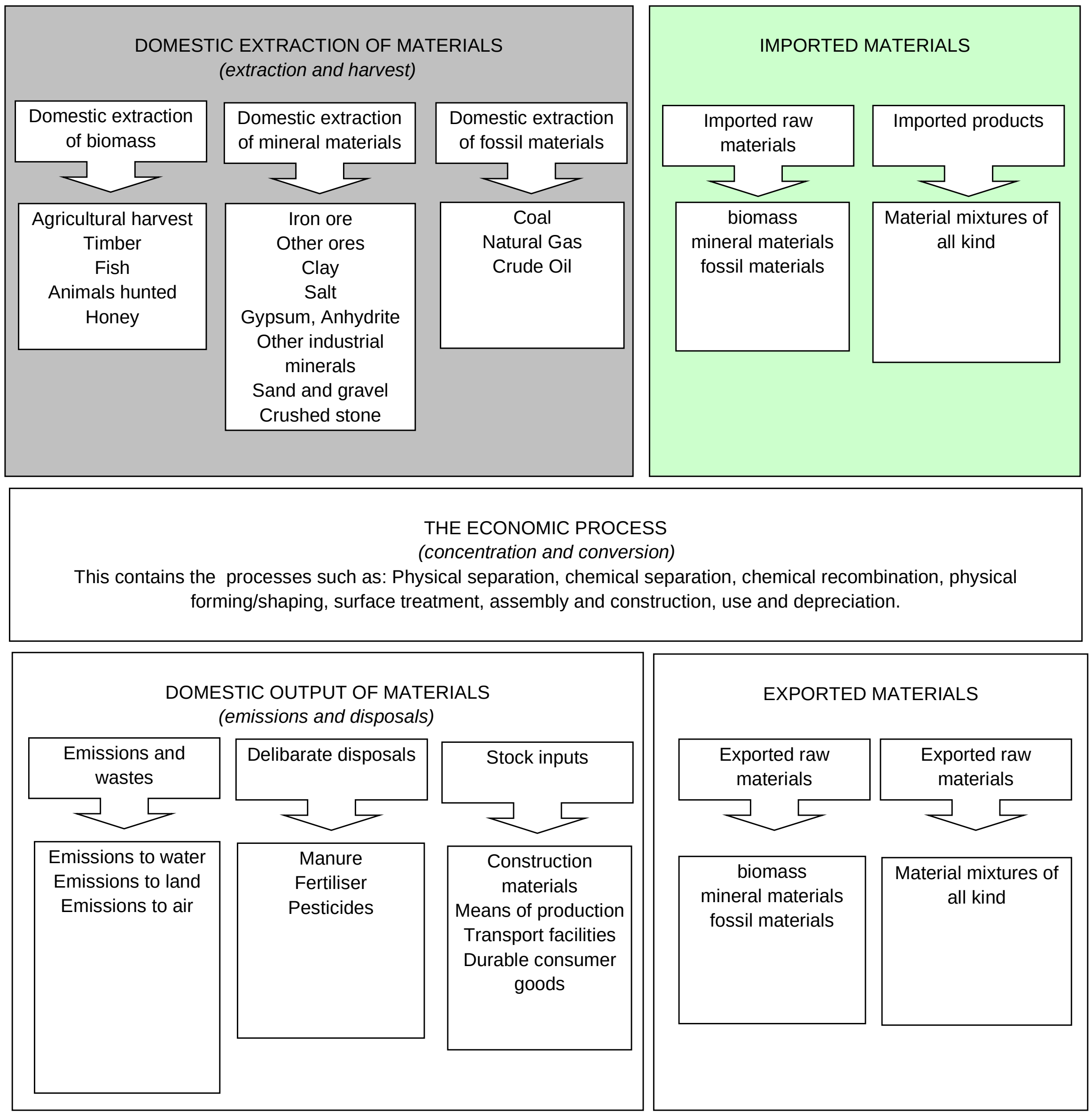
APPENDICES

Appendix 1. A systematic approach to Material Flow Accounting



Appendix 2. Categorisation of materials for the input account of the economy wide Material Flow Account

A) DIRECT INPUTS

These are flows that either directly serve to produce or reproduce the material stock of humans, livestock and artefacts. They should be categorised as follows.

DOMESTIC EXTRACTION OF MATERIALS

- Domestic extraction of water
  - Ground water
  - Surface water

- Domestic extraction of air
  - Air for breathing of humans and livestock
  - Air for combustion processes
  - Air for other technical use (e.g. fertiliser production, cement production)

- Domestic extraction of materials[24]
  - Domestic extraction of biomass
    - Agricultural harvest (e.g. crops, straw, fodder crops, vegetables, fruits, natural fibres, natural rubber, hay)
    - Timber (e.g. softwood, hardwood, cork)
    - Animal grazing
    - Plant biomass from "wild harvest" (e.g. mushrooms, berries, tubers, herbs, weeds, alga)
    - Fish (both wet fish and shellfish)
    - Hunted deer
    - Honey
  - Domestic extraction of minerals
    - Iron ore
    - Other ores (e.g. copper, lead, aluminium, nickel, zinc, tin, platinum, silver)
    - Clay (e.g. china stone, ball clay, potters clay, fire clay, oil shale, fullers earth, common clay and shale)
    - Gypsum and anhydrite
    - Industrial minerals (e.g. slate, calcspar, chalk, chert and flint, silicia stone and ganister, special sands for moulding and

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[24] Of course, also water and air are materials, but it is also confusing to subsume the material components, which dominate our daily life as other materials, like some studies do. Here, materials are explicitly defined as materials excluding water and air inputs but including their water res. oxygen content.

glassmaking, other silicia sands, fluorspar, barytes, witherite, iron pyrites)

Salt (rock salt, salt from brine)

Sand and gravel (from land, marine)

Crushed stone (china clay, limestone, igneous rock)

Domestic extraction of fossil materials

Coal (brown coal, lignite, and hard coal)

Crude oil

Natural gas

IMPORTED MATERIALS[25]

- Imported raw materials

  Biomass (food and live animals, beverages and tobacco, inedible biotic raw materials like for instance timber, cork, natural rubber, cotton, silk, hides and skins, etc).

  Mineral materials (crude mineral materials like iron ores, other ores, salt, crude industrial minerals, sand and gravel, etc.)

  Fossil materials (crude fossil materials like coal, crude oil, natural gas)

- Imported products (semi-manufactured or final products of all materials, usually appearing as a material mix of all material categories – biomass, minerals, fossils).

B) HIDDEN FLOWS

Hidden flows can appear both with domestic extraction and with imports. Nearly every domestic extracted raw material can cause a so called hidden flow like excavation and overburden in mining, side products from agriculture and fishing and so forth. Although these materials are mobilised within the extraction processes, these side products typically never enter the economy and therefore are not considered to be direct inputs. The methodology for accounting of hidden flows is still rather poorly developed. Hence, efforts to establish appropriate methods for certain input categories should be given support. Hidden flows of imported materials refer to flows, which are mobilised in a foreign economy to provide a raw material or a product for foreign trading. Here, it is even more in question how things should work methodologically. Should only hidden flows of the extraction process in other economies or also emissions and wastes going jointly with the production process providing final products in other countries be taken into account?

[25] Basically it should be differentiated between imported raw materials allocated to the three main raw material categories and imported products. The subcategories beyond that depend on how foreign trade statistics in a specific country are structured. Here is given a rather common example.

Appendix 3 Final table. A preliminary MFA for the UK, 1937-1998, in thousand tons

Appendix 4. Change within main aggregates in 5 years averages, in million tons

Domestic extraction of biomass

	Cereals and fodder crops	Potatoes and sugar beet	Fruits and vege-tables	Straw and hay	Timber	Animal grazing	Fish
	(m tons)	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*
1937-39	18.96	7.85	2.83	13.05	3.64	2.38	0.97
1940-44	25.02	12.01	3.75	14.48	3.47	2.62	0.30
1945-49	23.62	13.64	3.69	14.35	3.22	2.89	0.89
1950-54	23.78	13.00	3.41	13.86	3.63	3.08	0.95
1955-59	20.66	11.50	3.26	13.64	3.84	3.33	0.91
1960-64	21.03	12.71	3.53	14.86	3.43	3.76	0.81
1965-69	24.34	13.49	3.19	15.51	3.05	3.90	0.91
1970-74	31.86	13.50	3.01	13.72	2.15	3.84	0.96
1975-79	31.40	12.42	3.79	13.66	2.68	3.94	0.89
1980-84	36.04	14.95	3.66	14.32	3.19	4.00	0.75
1985-89	35.20	14.67	3.37	14.04	4.14	4.14	0.74
1990-94	31.70	15.88	3.21	13.43	4.75	4.36	0.67
1995-97	32.18	16.71	2.94	13.69	5.76	4.39	0.45

Domestic extraction of mineral materials

	Iron ore and other ores	Clay	Salt	Gypsum, Anhy-drite	Other industrial minerals	Sand and gravel	Crushed stone
	(m tons)	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*
1937-39	13.54	30.09	2.98	1.07	12.66	25.96	31.74
1940-44	18.11	16.32	3.43	1.22	11.09	27.74	30.61
1945-49	12.79	19.92	3.46	1.79	11.68	28.37	29.49
1950-54	15.28	31.14	4.34	2.50	21.07	46.70	41.77
1955-59	16.02	32.47	5.11	3.30	24.62	63.92	50.05
1960-64	16.29	35.58	6.19	4.05	27.62	89.62	67.08
1965-69	13.75	38.92	7.59	4.55	27.22	112.26	108.43
1970-74	8.42	35.11	5.82	4.12	25.97	122.82	142.18
1975-79	4.28	26.46	7.79	3.78	25.08	114.19	128.89
1980-84	0.57	20.86	6.99	3.05	17.97	101.89	112.31
1985-89	0.19	19.41	5.56	1.32	18.12	120.16	146.21
1990-94	0.01	11.80	3.14	0.00	14.83	102.22	156.47
1995-97	0.00	12.88	3.54	0.00	14.67	92.03	144.68

Domestic extraction of fossil materials/imported materials

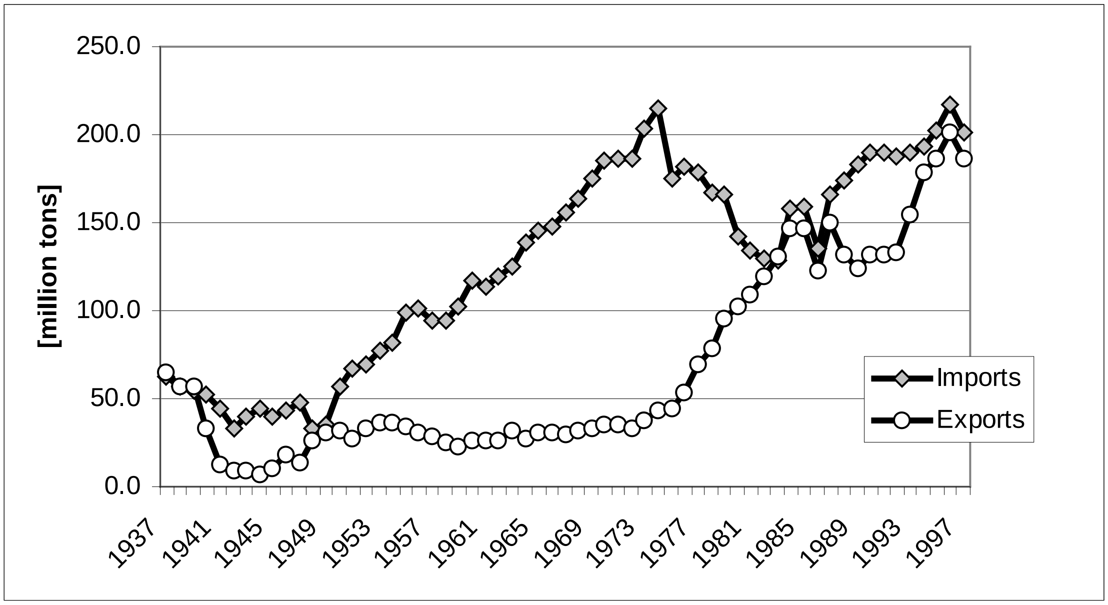
	Coal	Natural gas	Crude oil		Biomass
	(m tons)	*(m tons)*	*(m tons)*		*(m tons)*
1937-39	232.91		0.13	1937-39	33.01
1940-44	205.45		0.20	1940-44	17.00
1945-49	198.96		0.16	1945-49	18.15
1950-54	225.10	0.01	0.16	1950-54	22.59
1955-59	221.88	0.05	0.15	1955-59	27.49
1960-64	198.49	0.17	0.14	1960-64	27.69
1965-69	174.72	2.49	0.08	1965-69	26.81
1970-74	132.12	35.97	0.09	1970-74	23.66
1975-79	124.14	57.43	36.77	1975-79	22.38
1980-84	109.92	50.51	100.61	1980-84	17.66
1985-89	97.03	33.52	123.99	1985-89	19.24
1990-94	75.14	44.05	94.13	1990-94	21.44
1995-97	50.91	64.94	129.50	1995-97	25.33

Imported materials/exported materials

	Mineral Mater-ials	Fossil Mater-ials	Pro-ducts	Bio-mass	Mineral Mater-ials	Fossil Mater-ials	Pro-ducts
	(m tons)	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*	*(m tons)*
1937-39	7.65	2.08	15.03	0.80	0.57	48.30	9.70
1940-44	4.32	0.79	20.46	0.12	0.14	10.98	2.87
1945-49	9.59	1.06	10.70	0.51	0.33	11.18	7.68
1950-54	13.87	28.76	5.39	1.23	1.04	22.64	8.08
1955-59	17.59	46.03	7.09	1.26	1.38	17.51	8.28
1960-64	19.76	66.91	8.48	1.19	1.76	15.78	8.64
1965-69	22.07	98.11	10.76	1.72	2.46	15.42	11.24
1970-74	30.92	127.68	12.71	1.99	3.26	18.69	13.08
1975-79	37.14	94.39	19.79	5.11	8.21	34.39	20.40
1980-84	27.51	67.35	25.94	7.38	13.68	81.46	19.21
1985-89	34.68	70.60	38.53	10.54	11.90	87.76	24.72
1990-94	33.52	88.96	46.10	11.64	16.47	85.14	32.80
1995-97	41.06	81.10	59.28	14.18	22.85	110.35	44.10

Appendix 5. Diverse additional figures

Figure 7. The physical balance of trade for the UK economy, 1937 – 1998, in million tons



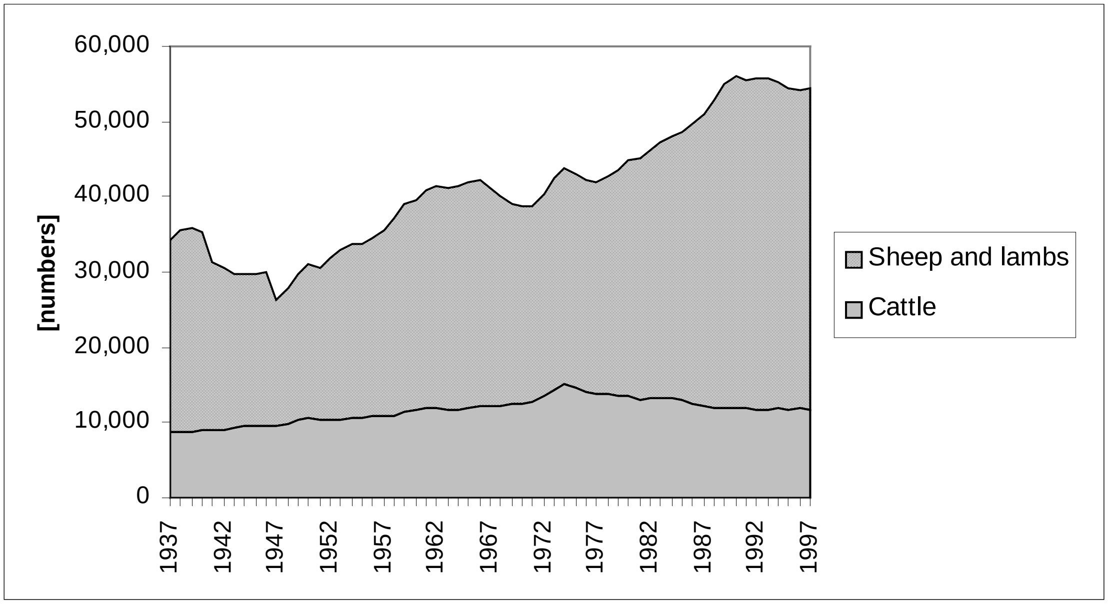


Figure 8. Numbers of cattle an sheep in UK holdings, 1937 – 1997, numbers